Multi-object tracking benchmark for livestock

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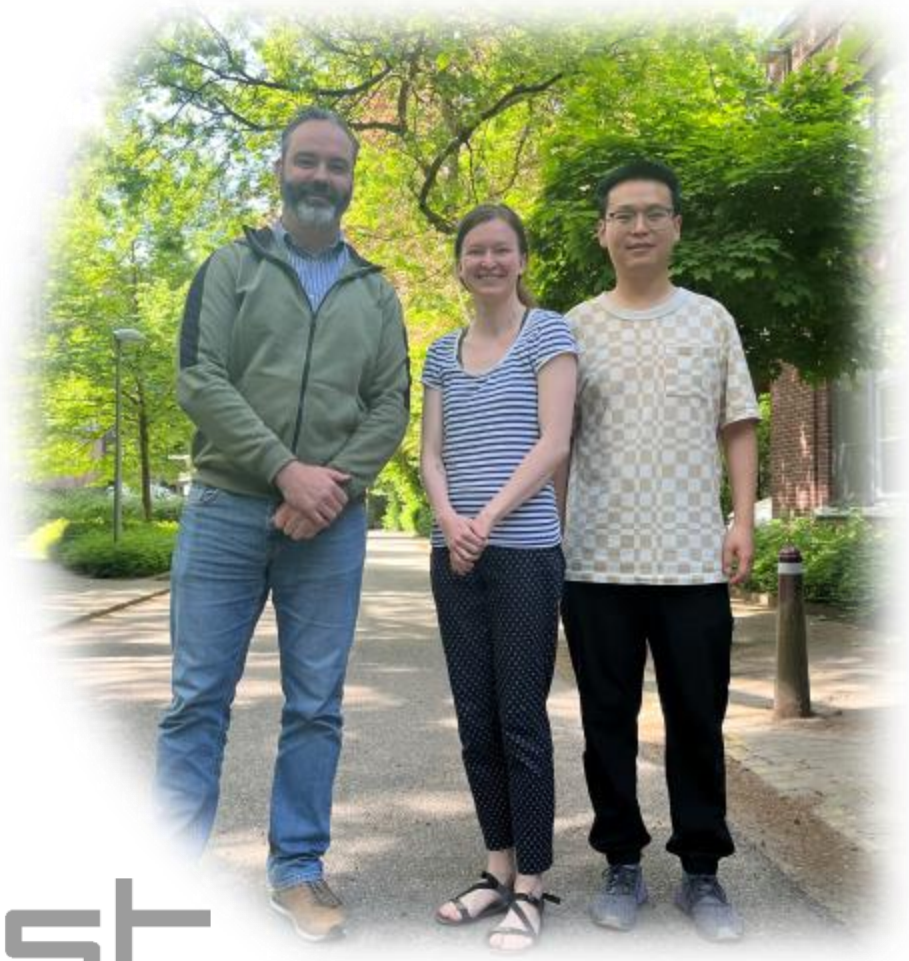
Motivation

"The lack of comprehensive benchmark datasets that capture full daily livestock husbandry limits real-world applicability. Future research must prioritise the development of large-scale, diverse MOT datasets and benchmarks that are representative of the challenges in livestock environments such as occlusion, complex behaviours, and long-term tracking requirements." (Nidhi et al., 2025)

Nidhi, M. H., K. Liu, and K. J. Flay. "Review: Multiobject Tracking in Livestock – from Farm Animal Management to State-of-the-Art Methods." *Animal* 19, no. 5 (2025): 101503. https://doi.org/10.1016/j.animal.2025.101503.

Introduction and collaboration

- Visited Prof. Tomas Norton and Dr. Dong Liu and the M3-BIORES (Measure, Model & Manage Bioresponses) group at KU Leuven, Belgium for 5 weeks in 2025
- Purpose of the visit was to start working on a **multi-species livestock benchmark for multi-object tracking**
- During the visit, we defined a rotated bounding box annotation protocol for cattle, harmonized it with existing pig annotation protocol developed by M3 group, and used the created protocol to annotate video data



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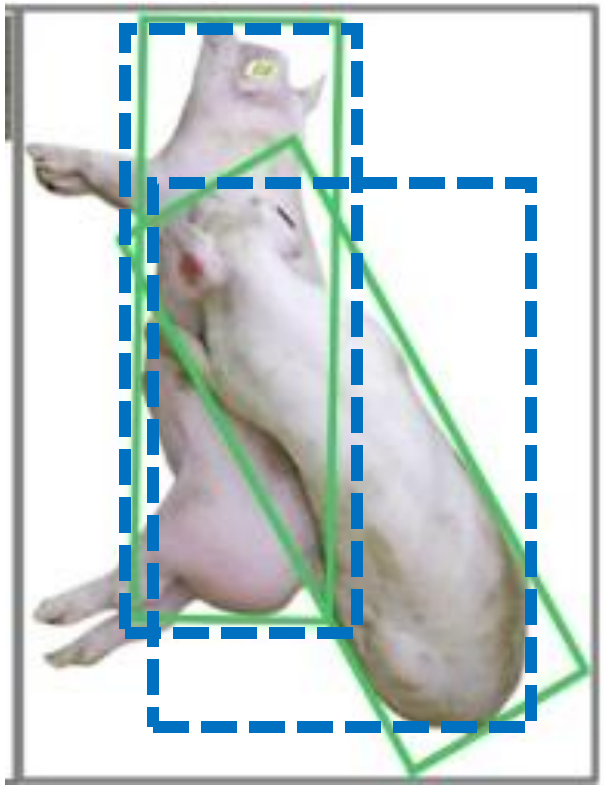
Rotated Bounding Box (RBB)

RBB detector significantly outperforms one based on horizontal bounding boxes (HBB) in densely arranged and arbitrarily oriented objects, e.g., in remote sensing (Wang et al., 2025) and densely-housed pigs (Liu et al., 2023).



Original: Liu et al., 2023. Blue dashes added

Liu, Dong, Andrea Parmiggiani, Eric Psota, Robert Fitzgerald, and Tomas Norton. "Where's Your Head at? Detecting the Orientation and Position of Pigs with Rotated Bounding Boxes." *Computers and Electronics in Agriculture* 212 (September 2023): 108099. https://doi.org/10.1016/j.compag.2023.108099.

Wang, Kun, Zi Wang, Zhang Li, et al. "Oriented Object Detection in Optical Remote Sensing Images Using Deep Learning: A Survey." *Artificial Intelligence Review* 58, no. 11 (2025): 350. https://doi.org/10.1007/s10462-025-11256-0.

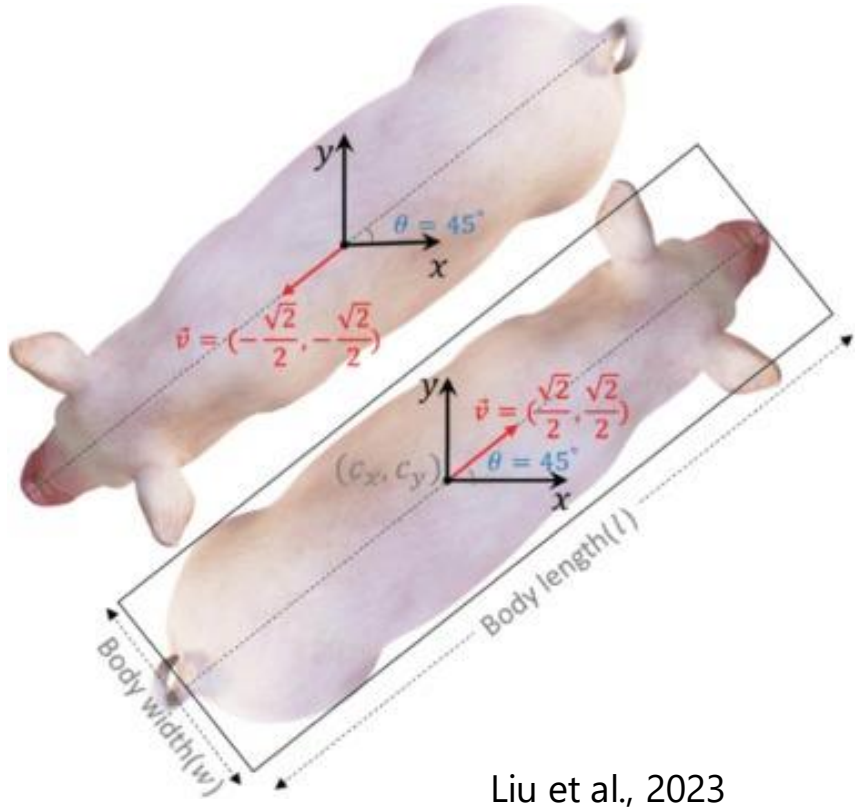
Clarification:
Oriented Bounding Box vs Rotated Bounding Box

- Oriented Bounding Box does not necessarily contain information on the direction
  - E.g. for YOLO-OBB, an OBB and its 180° rotation are identical, so rotation is defined modulo 180° - we cannot tell the head from the tail!
- Rotated Bounding Box typically:

$$RBB = (x, y, w, h, \theta),$$

where θ is the uniquely defined angle of the bounding box, giving us unambiguous direction.

- Direction where the animal is facing is critical information for understanding animal behaviour



Liu et al., 2023

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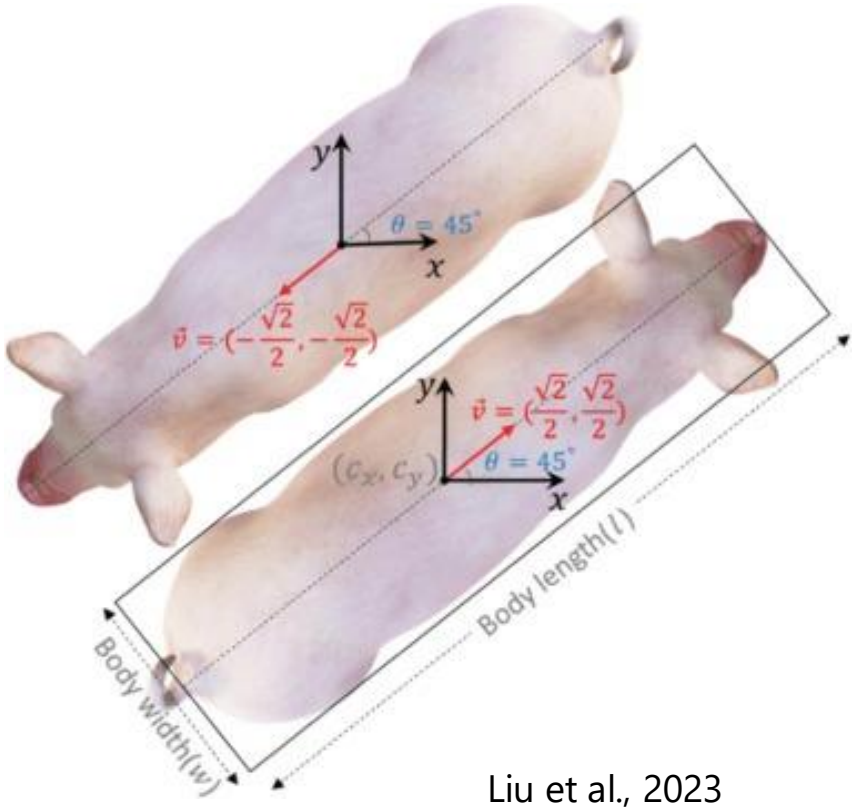
Rotated Bounding Box (RBB): angle discontinuity problem

Problem: Rotation values $\theta \in [-\pi, \pi]$ jump from $-\pi$ to π, where small angle changes can cause huge losses.

Solution: Encode object angle into a 2D Cartesian representation using $(cos(\theta), sin(\theta))$ pair, creating a continuous, unambiguous representation for every $\theta \in [-\pi, \pi]$ (Tu et al., 2021). Encode pig angle as a direction vector $\vec{v}$ and use cosine distance loss when training (Liu et al., 2023).



Liu et al., 2023

Liu, Dong, Andrea Parmiggiani, Eric Psota, Robert Fitzgerald, and Tomas Norton. "Where's Your Head at? Detecting the Orientation and Position of Pigs with Rotated Bounding Boxes." *Computers and Electronics in Agriculture* 212 (September 2023): 108099. https://doi.org/10.1016/j.compag.2023.108099.

Tu, Huahong, Siyuan Peng, Vladimir Leung, and Richard Gao. "SoK: Vehicle Orientation Representations for Deep Rotation Estimation." arXiv:2112.04421. Preprint, arXiv, December 10, 2021. https://doi.org/10.48550/arXiv.2112.04421.

Harmonized annotation protocol

- Compact box
  - The body and head are fitted to the box ignoring the tail, ears and legs, and additionally for cows, udder.
  - Bounding box should be tight and not include space outside the required extreme points of body and head.
- RBB
  - The basic principle is to mark the orientation to the face side of the animal. The more precise protocol to define the orientation unambiguously is species-specific.
  - Geometric parameters (body centre, length, width, and yaw angle) are parameterized by box centre, long edge, short edge and the direction vector.
- Structure and occlusion
  - Annotate all animals that have some head or body area visible, even if they are located at the edge of the image. Estimate the bounding box outside the visible area.
  - If occluded by structures or other animals, estimate true location and mark the bounding box based on estimation.

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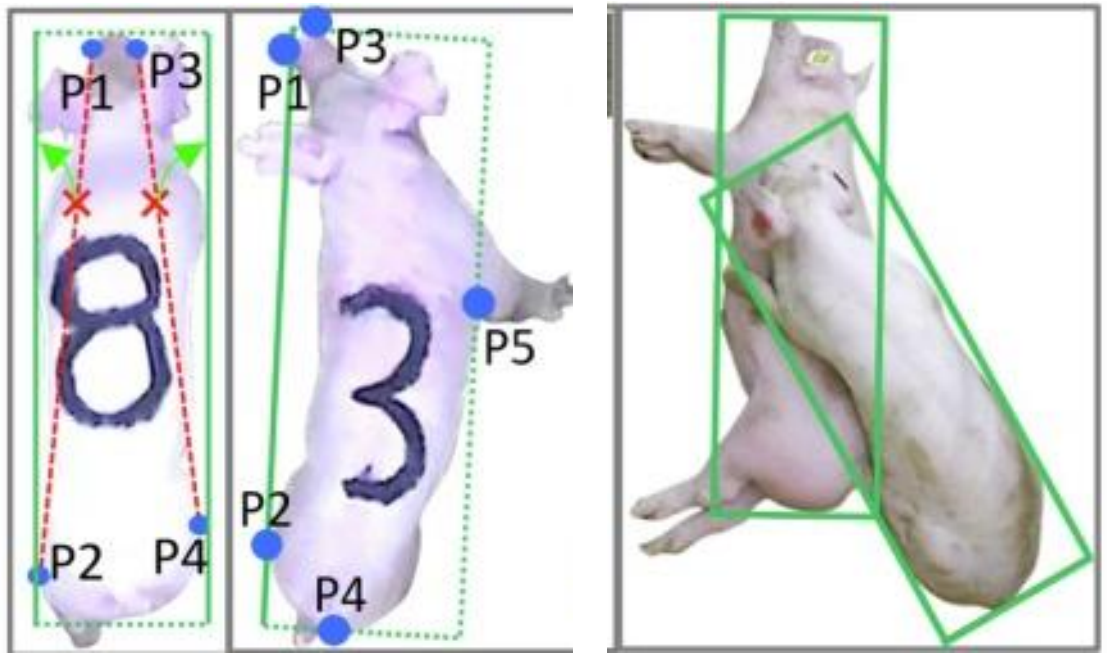
Annotation protocol: Pigs

- Rule 1: Pig in an arbitrary position and orientation can be uniquely defined for a) for standing pigs and c) for lying pigs.
- Rule 2: When pigs twist the body, we first define a tangent line (solid green line in b) through the edges of snout (P1) and hip (P2), two perpendicular lines and one parallel line are defined subsequently (dotted green line in b) which are tangent to P3, P4 and P5.
- If not sure about when to apply rule 1 or rule 2, we try to link snout edges with hip edges (P1 to P2, P3 to P4). If the lines pass through the body (red dotted line in a), rule 1 is applied. Otherwise, rule 2 is applied.



a) b) c)

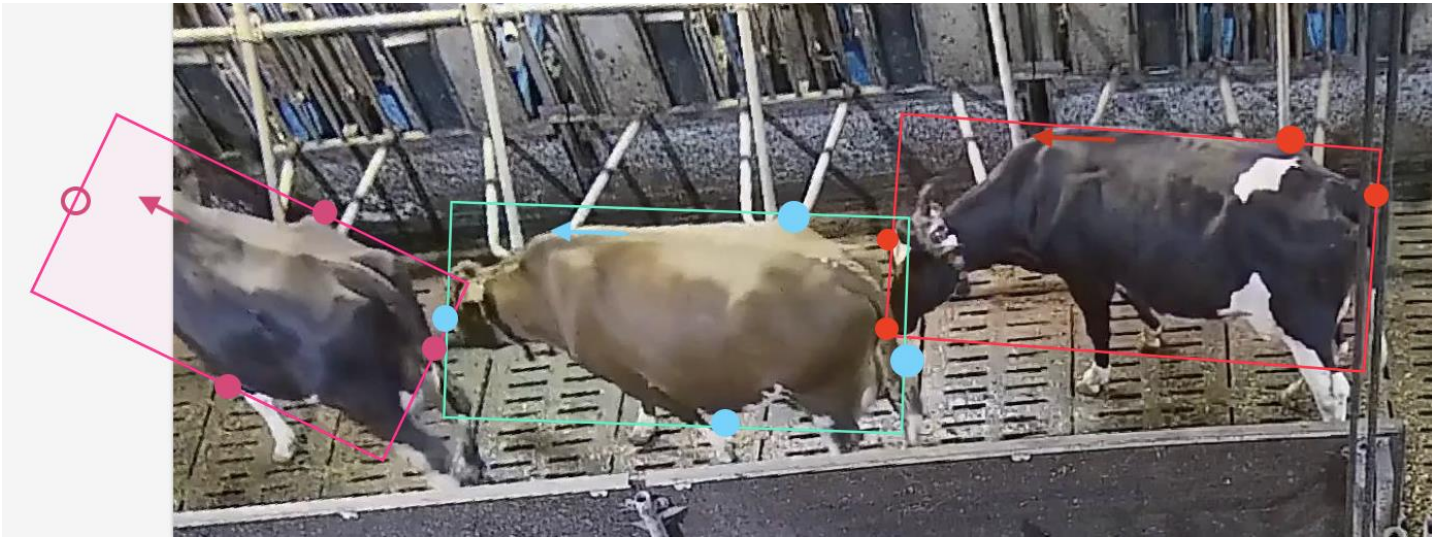
Liu et al., 2023

Annotation protocol: Cattle

1. For the correct rotated bounding box orientation, start with marking the orientation parallel to the orientation of the withers (the ridge between the shoulder blades of the cow). Even if the neck is strongly turned, orient the bounding box based on withers.

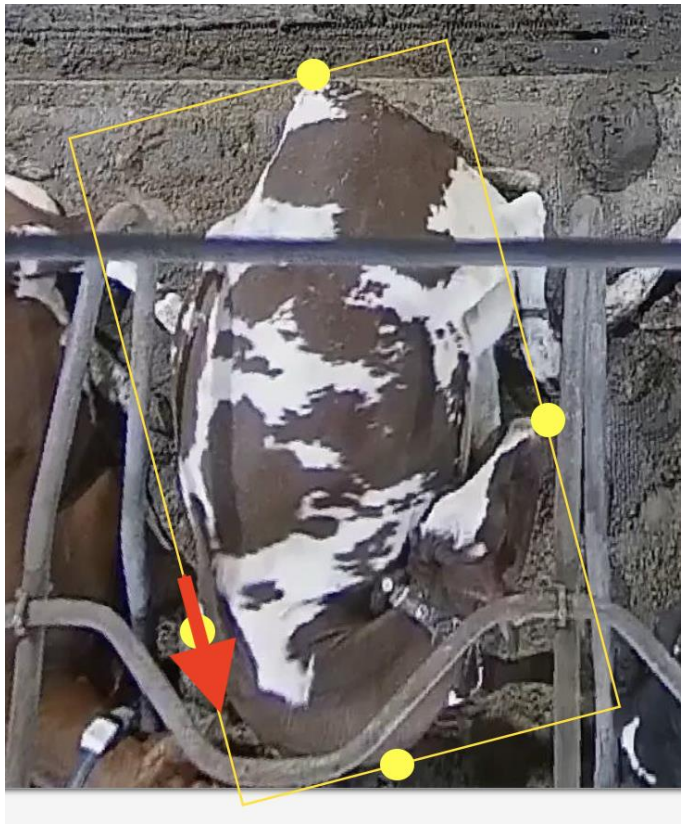
Annotation protocol: Cattle

2. Once the orientation of the withers is determined, extend the bounding box to cover the body, neck and head of the cow, including thighs. Typical extreme points are at the base of the tail at the pin bone, muzzle, forehead, and along the neck, stomach or back.



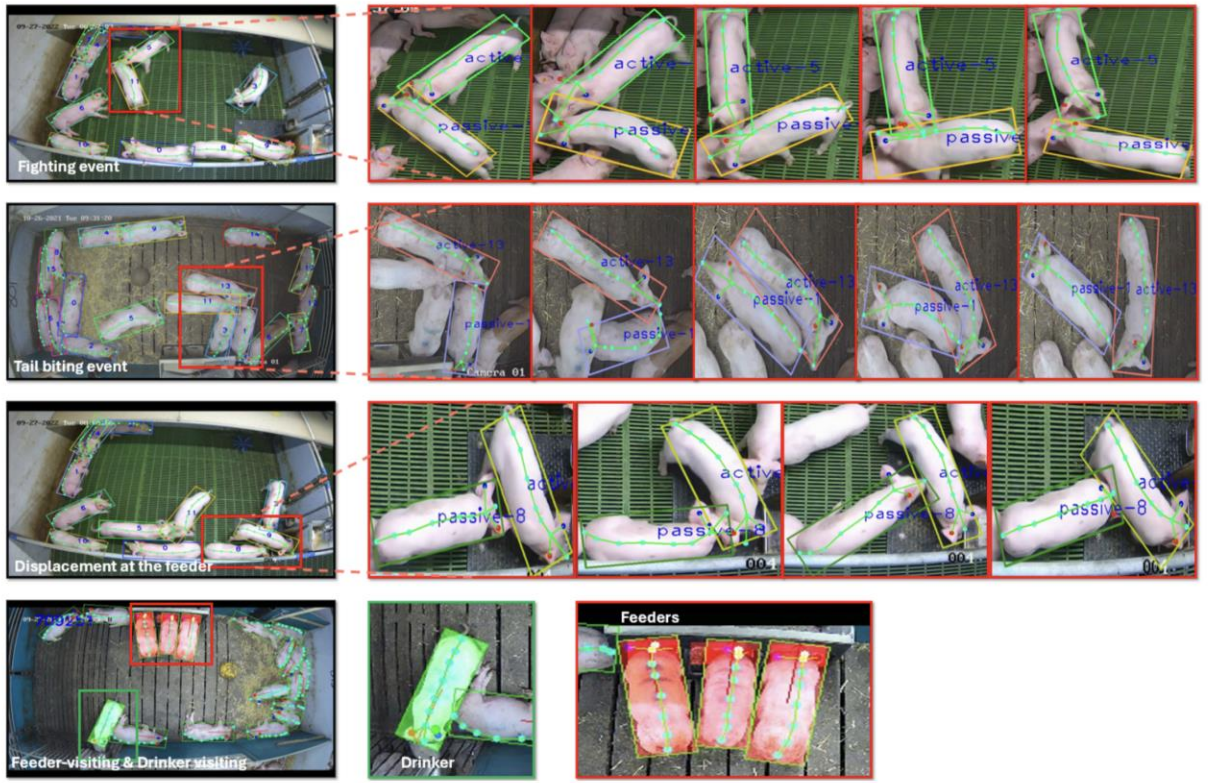
Annotation protocol: Cattle

3. It is not always easy to tell what direction the withers are or where the spine is due to lighting, shadows, coat patterns, especially if the cow is turning around fast with rotated head. In this case, orientation can be defined along the visible edge part of the cow closest to withers.



Dataset summaries: Pigs

- Data collected as part of two different experiments
- 6 pens
- Weaner and finisher pigs
- Group size 9–16 pigs per pen
- 56 pigs in total
- RGB cameras,1920 × 1080 and 1770 × 1130

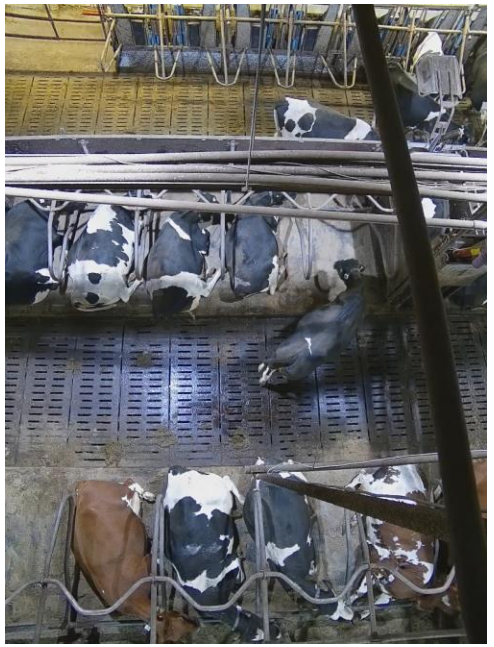


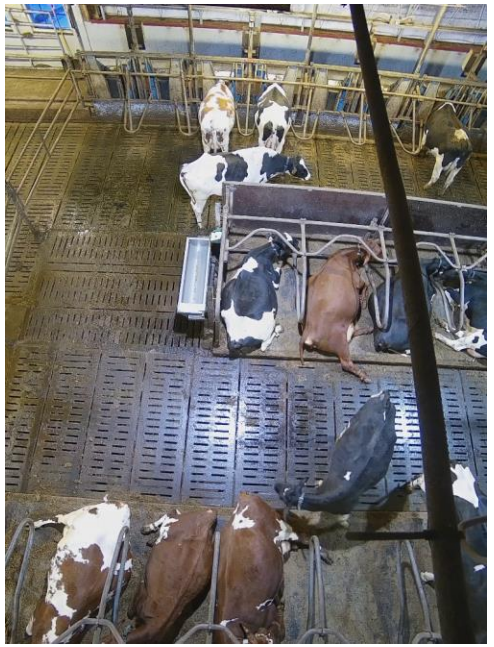
More details in Liu, Dong, Andrea Parmiggiani, Mona Lilian Vestbjerg Larsen, Keelin O'Driscoll, Guilherme Amorim Franchi, and Tomas Norton. "You Only Look at Triggers: Spatiotemporal Behavioral Proposal Generation for Group-Housed Pig Interactions." *Computers and Electronics in Agriculture* 246 (May 2026): 111562. https://doi.org/10.1016/j.compag.2026.111562.

Franchi, Guilherme A., Jacinta D. Bus, Iris J. M. M. Boumans, Eddie A. M. Bokkers, Margit Bak Jensen, and Lene Juul Pedersen. "Estimating Body Weight in Conventional Growing Pigs Using a Depth Camera." *Smart Agricultural Technology* 3 (February 2023): 100117. https://doi.org/10.1016/j.atech.2022.100117.

Dataset summaries: Cattle

- Data collected on Luke Maaninka research barn in Finland, 2021
- 2 departments with 2 cameras each, 24 lactating cows in each department
- Free stall barn
- Robot manure scraper, individualized feeding system
- RGB cameras 1944 × 2592






More details in Dairy cow re-identification and tracking using computer vision (Master's thesis, Hilla Fred, University of Helsinki, 2021)
http://hdl.handle.net/10138/351208

Dataset summaries – annotated data

Species	Type	Videos	Mean length	Total length	Total frames	Individual animals per pen or department
Pigs (*Sus scrofa domesticus)*	Finisher and weaner	19	34m 27s	467m 28s	140241	9-16
Cattle (*Bos taurus*)	Lactating cows	6	7m 25s	44min 33s	13365	24

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Benchmark evaluation

- Standard multi-object tracking metrics, with emphasis on higher-order matching accuracy, e.g.
  - Higher Order Tracking Accuracy (HOTA), Fragmentation, Association accuracy (AssA)
  - Multi-object tracking accuracy (MOTA), Multi-object tracking precision (MOTP), IDF1
- Domain-specific properties we consider on the benchmark and evaluation metrics
  - Cows stay in one place for a long time
  - Loose housing systems for cows are large areas, difficult or impossible to cover with a single camera, resulting in cows moving out of frame and re-entering

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Conclusion: Benchmark goals and work in progress

- We will publish an open dataset in Zenodo
  - Including public RBB detections for part of the test data, to allow pure evaluation of tracking methods
- Baseline tracking results for performance lower bound
  - E.g. SORT (Bewley et al., 2016), StrongSORT (Du et al., 2023)
- Also planning to host the benchmark on a competition platform
  - Evaluation of new models easy and transparent
  - Ground truth for test data kept private to ensure fair evaluation
- Versioning: new datasets can be added as more data is created

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Thank you!

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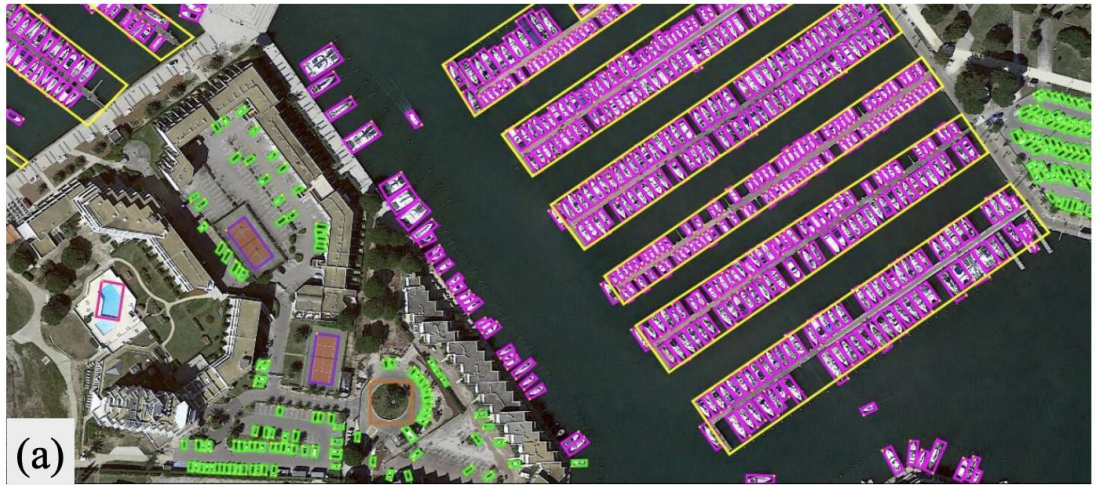
Why not corner point angle representation?

- Corner point representation of RBB without explicit angle (Xia et al., 2019)
  - Requires consistent implicit ordering of the bounding box points
  - If rectangularity is not enforced, computing overlap between two general polygons, not rectangles

  → harder optimization



[2]Xia, Gui-Song, Xiang Bai, Jian Ding, et al. "DOTA: A Large-Scale Dataset for Object Detection in Aerial Images." arXiv:1711.10398. Preprint, arXiv, May 19, 2019. https://doi.org/10.48550/arXiv.1711.10398.

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Some existing datasets

- PigTrack (Henrich et al., 2025), HBB benchmark
- PigTracker (Lin et al., 2026), use RBB. Data available on request.

- MooCap (Noronha et al., 2026), keypoints
- MMCows (Vu et al., 2024) HBB, 15s intervals
- CattleEyeView (Ong et al., 2023) keypoints, alley

- GooseBehaviourTrack (Guo et al., 1.9.2026), use RBB. Data available on request.